

THE PRESENT STATUS OF AGRICULTURAL METEOROLOGYIMPORTANT NOTE

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Introduction

This survey is based on experiences gained and information received during a recent (1954-5) tour of eleven countries, namely, France, Eire, Norway, Sweden, Denmark, New Zealand, Australia, South Africa, Netherlands, Belgium and Germany.

It is of necessity incomplete, for three reasons:- Firstly only eleven countries were visited and there are obviously other countries in the world in which important work is proceeding. Secondly it is idle to pretend that every aspect of the work was covered in every country visited; time, space and money precluded perfection. Thirdly the diversity of subjects which can be included under the heading "agricultural meteorology" is such that an exhaustive survey would run to many thousands of words.

Nevertheless this survey is intended to underline the more interesting and most promising subjects which were encountered. The subjects are treated alphabetically to avoid any invidious ranking in order of preference or importance. The bibliography has been arranged section by section; the references refer exclusively to papers and reprints which were collected during the visits, and must in no circumstances be regarded as comprehensive.

1. Animals

Discussions at the meeting of the Commission for Agricultural Meteorology held in Paris in 1953 indicated that the effects of weather on animal breeding, animal health and animal productivity had not been a subject in which much work had been done. Conversations during the tour confirmed this, but it was not easy to find the reason. Partly, perhaps it was due to the fact that there are fewer research establishments dealing with farm animals than there are dealing with plants; partly it may be due to the possibility that workers in problems of animal disease have tended to remain separate from other workers; collaboration in this field is not a common practice. I do not think that lack of work is due to lack of problems. The general problems are those of the zoning of breeds and the introduction of new varieties or species. Among cattle, for example, the ability of the Hereford to withstand a wide range of climatic conditions successfully is very marked. There are many sheep breeds in Britain, most of them with fervent supporters, but effectively there seems to be only one, a Romney cross, which is popular in New Zealand, and that was one of the first to be introduced there. It seems sensible that, from a climatic point of view, Britain may have too many breeds and New Zealand may have too few, but there is little research work that can help to substantiate this.

Three particular examples come to mind regarding the application of meteorology to more specific problems. One case was that of the Isle de France sheep, a breed which is kept almost uniquely around the Paris area because the lambs gain weight rapidly and are suitable for the city meat market. During winter the animals have to be kept indoors and were found to be suffering from a disease which impaired the quality of their wool. This was traced to a problem of temperature and humidity in the winter quarters and improved ventilation and drying conditions caused the disease to die out.

Another case did not have such a happy result. Examination of past records in New Zealand seemed to imply that a given type of weather always preceded considerable outbreaks of facial eczema in sheep. This weather occurred in 1953-54 but the incidence of the disease was almost nil.

The third case was somewhat involved. The germs of a human disease in South Australia were found to be carried by birds which came to the state from Queensland. This emigration only occurred when there was an excess bird population in the north-western state. The excess bird population was a result of a good food supply the previous breeding season and this depended on the monsoon rains. Rain in Queensland thus led, via the birds, to disease outbreaks in South Australia!

Reverting to the general problem, livestock improvements in any area seem to follow three lines of action; skilled breeding from existing stock (possibly using artificial insemination), sensible introduction of exotics, and better levels of feeding. In regard to artificial insemination it was stated at Rambouillet in France that they only issued ram semen on days which can best be described as "post-cold frontal"; the percentages of "takes" was appreciably less on dull cloudy days. It has been found at the National Institute for Research in Dairying that the secretions of cows change their physical properties very considerably during oestrus. If this change is influenced in extent by current weather, a link between weather and conception may be established.

The meteorologist cannot help much at present in regard to the proposed introduction of foreign breeds of farming animals. He may have climatic data available for both the old and the proposed new areas, but no one is certain as to how such data can be interpreted in terms of animal productivity. Nevertheless I do not think that the meteorological factors are as critical in this matter as they are in the case of plants.

A meeting of the European Association of Animal Production was held at Lucerne in 1954, to discuss the subject "The Influence of Climate on Animals and Animal Production". I was not able to attend and have not yet seen a published report.

2. Buildings

Modern farm buildings are certainly being planned more efficiently by using the type of factor which emerges from a time and motion study. On the other hand there is reason to believe that the reverse process is taking place in regard to our ability to create and maintain a desirable local climate. The deterioration in quality of food between field and consumer is extremely important, and much of the troubles of deterioration can be laid, literally and metaphorically, at the door of the packing shed. Bad temperature conditions during and immediately after packing leads to troubles which cannot be halted by refrigerator vans and cold storage.

The old Roman type of farmstead, with buildings standing four square around the stockyard may have been built with defence considerations in mind, but exactly the same design is met with in old Scandinavian farms. The compact hollow structure gives excellent protection against windy or wintry weather; draughts are absent and the walls are thick and virtually non-conducting of heat. The same cannot be said of many modern structures and the opening-out of the approaches to a farmyard to permit entry of machinery has lead to many wind problems in regard to living conditions for stock.

Conditions for the housing of stock are particularly interesting in regard to pigs. The old pigsty was dirty and unhygienic, the new one is clean and superficially attractive, yet if there are large ranges of diurnal temperature due to draughts or thin walls, the small pigs die of pneumonia. It was noticeable that the Danish piggeries were of far thicker construction than many English types, the roof in particular being designed to cut down heat loss. The best type of new pigsty seen was in New Zealand and was designed to eliminate draughts as well as to avoid the chance of the sow lying on top of her litter. It consisted of two concentric arcs of a circle; the inner arc ran from 200° through 360° to 160°, the outer arc from 030° to 330°. The inner circle was too small for the sow, but was the gathering place for the litter as it was warmed by an overhead infra-red lamp. Experiments were in progress using thermographs to test the effects of the various materials used for construction and various types of liftable roof.

3. Control Chambers.

Control chambers are by no means inexpensive but they are a very popular item of research equipment, especially among plant physiologists. They range from underground chambers in which, theoretically, complete control is possible, to air-conditioned greenhouses. The main meteorological objections to their use,

or rather to the validity of deductions made from results obtained by their use, are as follows:-

- (a) Inadequacy of the intensity of the artificial total radiation, (this is particularly important in cases where the research is attempting to examine the water use of plants).
- (b) Absence of "natural" temperature and humidity gradients in the air and temperature gradients in the soil (especially if pots or trays are used).
- (c) Absence of diurnal changes (although several attempts have been made to overcome this).

A controlled glasshouse at Brussels University was particularly interesting. Conditions were reproduced similar to those in the Belgian Congo, including diurnal range and occasional thunder-showers: the total radiation falling on the plants was about half the true value but otherwise the external meteorological conditions were correct and the growth of the plants was not dissimilar to those in the Congo.

It is obvious that control chambers must be used to assist laboratory research but I consider that, in view of their limitations, it would be wise to use them for the purpose of obtaining comparisons between plant behaviour rather than establishing any direct weather-plant relationship. A possible exception is that of experiments in photoperiodicity. Nevertheless results found in control chambers can be used to design field experiments; they are a sound starting point and can be useful provided that the limitations are known. The main danger arises from the possible idea that a true artificial climate has been reproduced when only a limited number of weather elements have been considered.

4. Erosion.

"In a general sense, all soil erosion phenomena are caused by a flowing movement of soil particles under the influence of gravity, water and wind. This movement varies from the relatively dry flow of creep erosion to sliding in slip erosion and to rapid flow with increasing moisture in earthflow, sheet, and river erosion. The most rapid flow of all - that of wind - results in wind erosion." (D.A. Campbell)

Although uncontrollable meteorological factors play a large part in creating areas of dangerous erosion, the ill-advised actions of men throughout the ages are not without responsibility in the matter. Sand-storms and rising sand in deserts are inevitable whenever the appropriate weather conditions occur. In areas of light rainfall the similar phenomenon is often known as "blowing", and many of the factors which influence the frequency of blowing are within human control. Many nations have had occasion to forget the sequence of natural land use which runs from dairy farming in an 'adequate' rainfall regime, through arable farming where the growing seasons are drier, to areas of nomad grazing where rainfall is infrequent and irregular, and finally to the sterile arid desert. The greed for wheat and bread and ignorance of the true water balance has led to the ploughing up of steppe country for grain. The cereals take more water from the soil than is replaced by the rain during the fallow periods; the soil progressively dries out and ultimately "blowing" becomes so frequent that the top soil is removed and a desert is created. This is probably what happened when the Romans used North Africa as a granary; in more recent years it has occurred in the United States, in Australia, and possibly in southern Russia. Most countries are now aware of this misuse of land and the erosion evils which follow but it must be stressed that a relatively small climatic change in rainfall frequency or amount can have a very significant effect in the marginal areas and wind erosion is very much an irreversible process.

It is not only wind erosion that is the danger in areas of low rainfall. When the rains do come they may do so in the form of heavy storms. Dry soil

does not absorb rain readily and especially if it 'caps' or 'pans' easily, there may be a very rapid surface run-off. The most obvious effects of erosion that are visible in a low rainfall area are the gullying and river erosion which follow the heavy storms and sudden spates. A meteorologist needs to know far more about rainfall intensities and frequencies before much help can be given to assist in the solution of this problem.

On the heavier rainfall areas the form of land use which leads to slip and sheet erosion is the burning of natural forest and its replacement by poorly kept and over-stocked grass. Particularly on slopes it is unwise to take grassland too far into high-rainfall areas. The extent to which erosion has occurred in a country such as New Zealand is indicated by the following estimates for South Island:- "Of $8\frac{1}{2}$ million acres of high country surveyed, 80% is significantly eroded, and 25% has lost more than half of its topsoil".

Further research in erosion mechanism and erosion control needs meteorological help particularly in relation to water balance relationships and rainfall statistics. The French view of the problem is "il est bien certain que l'on ne peut pas supprimer tous les mfaits du climat, mais ceux-ci peuvent être largement amoindris et réparés par des pratiques culturelles appropriées".

Erosion is not supposed to be a serious problem in Britain but it can and does occur. The experiences gained in countries where it is a greater menace can be of use in combating its effects here, where there is little or no excuse for its occurrence at all.

5. Evaporation and Transpiration.

A meeting was held at Wageningen, Holland in the autumn of 1955 to discuss aspects of physics in agricultural problems and the main subject was that of evaporation and transpiration. The meeting was attended, not by government representatives, but by physicists, soil scientists, meteorologists, plant physiologists and agronomists who had been, for the most part, working in the subject. Countries of north-west Europe were well represented, but there were also visitors from Canada and Australia, and as a result it was possible to reach conclusions which took into account a variety of experience.

The conclusions stressed the vital importance of further knowledge regarding the movement of water from the soil to the atmosphere and asserted that the fundamental role of the physicist in agriculture should be in this field of work. The importance of the basic research (of the type proceeding at Aspendale, Victoria, and Cambridge, England) was recognised, but the direct application and interpretation of such work in practical field problems is not easy. The instruments and observational technique are delicate and the calculations take considerable time to obtain results pertaining to limited areas and limited periods of time. Extrapolation is difficult, and the work at the present juncture is essentially microphysical rather than agricultural research.

The need for the existence of empirical or semi-empirical formulae using more readily obtainable data to obtain results of the correct order for use in practical problems was recognised. Formulae which are based on a limited number of meteorological parameters (such as temperature and day length) were regarded as having restricted possibilities; their chief advantage lay in their application to areas where meteorological data was very scanty; the degree of accuracy was bound to be variable. Other formulae (such as Penman's) using more logical physical arguments gave more promise, although again there were certain limitations. The conference suggested in their conclusions that such formulae had been used with considerable success in questions regarding the evaporation from open water and also in transpiration problems when water supply was a non-limiting factor (e.g. controlled irrigation). Under other circumstances, when moisture stresses occur, and the movement of water from the soil through the root hairs, through the plant and through the stomata to the atmosphere is restricted by non-meteorological factors, further assumptions have to be made to apply the concepts of potential transpiration. The results so obtained have to be treated with a fair degree of caution.

Direct check of the microphysical methods and the semi-empirical approach is theoretically possible by measurement of the changes in soil moisture, but in practice there is yet no really satisfactory method of making this measurement in the field. Each method has its advantages and limitations, many work satisfactorily in the laboratory but break down under field conditions; lysimeters and evaporation pans (or tanks) all have their difficulties of construction, exposure, handling and interpretation.

The ideal would obviously be for any experiment to be carried out using a variety of methods, but this state of affairs cannot easily be attained. Experimentation in any one method is difficult enough and very few workers in the subject have sufficient collaboration, time or money to carry out their work under ideal conditions.

The Wageningen meeting finally stressed the need for immediate practical help as well as the need for continued basic research. Present field investigation must use the best information that is readily available; it cannot wait until perfection is attained. A meeting of this kind is extremely helpful in assisting present practice as well as directing future research activity; this help often appears in the form of learning from the mistakes of others. Mistakes or unsuccessful research attempts are rarely subjects for publication, so that this type of advice can only be obtained by personal contact.

This important aspect of 'negative' help was apparent at a Soil Moisture Conference I attended at the Dominion Physical Laboratory, Wellington, New Zealand. It was, in fact, so much in evidence that the soil scientists, who had been trying to measure water-loss suggested that the best method was to calculate it, and the meteorologists who had tried calculation and knew its limitations had come to the exactly opposite conclusion: I was impressed by the enthusiasm shown at the meeting which has been called to consider scientific help to the rapidly growing interest in irrigation problems. It is a great pity that distances render difficult the exchange of views on current research projects; delays in publication often mean that knowledge in New Zealand of European work is several months out of date.

The work of the Division of Meteorological Physics of the Commonwealth Scientific and Industrial Research Organization, Australia has already been referred to and considerable progress has obviously been made there in recent years in instrumentation and observational technique. As the name of the division implies the work had been essentially treated as research in physics, but it is possible that the experience gained in this manner will be applied to agricultural research problems. Long-term plans also suggested that much of the time spent in calculation might be cut out by suitably designed electronic assistance. They have also been concerned with tests of the use of cetyl alcohol as a film to reduce evaporation loss from a reservoir. This may be very important in hot climates. Other work in Australia on evaporation and transpiration has chiefly been concerned with empirical formulae designed to provide values of actual water usage in near-drought conditions. Such formulae have proved of use in areas where they originated but extrapolation to other areas and other crops involves a larger degree of possible error, a fault inherent in all empiricism. Some field experimental work in Northern Territory has provided some extremely interesting data of crop behaviour under monsoon sub-tropical conditions. The water loss from three different types of crops under non-limiting soil moisture conditions was virtually the same, but the departure of actual transpiration from the potential was different from crop to crop as the soil moisture decreased. Another feature of this type of climate is that even when the soil is amply supplied with moisture the midday demand by meteorological conditions for transpiration is at too high a rate for the plant to comply with. Wilting thus occurs and cannot be avoided by adding more water to the soil; the plants recover as the heat load from the sun decreases. A similar state of affairs occurs in bad glasshouse management in this country.

Field experiments involving the measurement or calculation of transpiration by more than one method are in progress near Copenhagen in Denmark and near

Groningen in Holland. The latter experiment is interesting in that use is being made of what are, in effect, lysimeters on three scales; the water balance of a plot, a field and a farm can be assessed. Another experiment near Castricum in Holland measures the actual water loss from four large deep lysimeters, the surfaces of which are sand dunes, natural scrub, deciduous trees and conifers. Tank measurements in the middle of the Zuider Zee show very close agreement with (Penman) calculated values. Other work at Wageningen shows that calculated losses from grass are of the right order. Holland has used Piché evaporimeters with a porcelain base replacing the filter paper and the results have been encouraging, but German values of Piché readings throughout their larger and more diverse country would indicate caution in assuming a strict one-one correspondence between such readings and actual evaporation. Potential evapotranspirimeters at Valentia in Eire were giving consistent readings after initial leakage trouble. The use of small lysimeters for measurement of potential water loss seems to have far more justification than for measurement of actual water loss. In hot climates particularly the effect of truncating the soil column may be far greater than is realised. The Germans make much use of readings from small lysimeters of the Popoff type, and interesting comparisons can result from such data.

There were other interesting tank or pit experiments in progress at places like Versailles, Montpellier, Wageningen, Adelaide (I.C.I. salt works) and Hamilton, New Zealand. Meetings such as the informal one in Holland this year are likely to be repeated at intervals of 3 years; the next one will probably be held in Britain. So important is this work, so great the difficulties and so manifold the implications that it is only by interchange of current experience that countries can help each other adequately.

6. Forecasts for Agriculture.

Farmers throughout the world seem to treat weather forecasts in much the same way. Roughly, there are two schools of thought. The majority regard them as a subject for a joke or complain bitterly about their inaccuracy; such farmers are also often strong supporters of the local "expert" especially in regard to long-range forecasts. When cross-examined, it is generally found that the evidence for their faith in the amateur is just as flimsy as the evidence for their universal condemnation of the professional; their ignorance was often only equalled by their prejudice. The minority realise the difficulties under which the forecaster works and appreciate the inevitability of forecast errors, but most of them also believe that the errors are too frequent and too significant for them to make much use of published forecasts as a regular help in planning their agricultural programme. They point out that often their work must proceed whatever the weather and they have little freedom of choice of action, although they do admit that an accurate forecast would help at certain critical times of year e.g. sheep shearing, grain harvest, etc. I did not meet anyone who spoke in terms of unreserved praise.

Almost all the agricultural research workers belong to the second group; they realise the limitations and accept them as an unavoidable risk. It is rarely, however, that they request more forecast advice; they are usually far more interested in other branches of meteorology. It was significant that whenever one was introduced as "agricultural meteorologist" and met the reply "Oh, yes, do you do the forecasts for farmers?", the person concerned was generally not only ignorant of meteorology but unaware of his own ignorance.

From the meteorological side there were two ever-present worries; firstly the forecasters were not aware of the significance of the weather and its effect in detail on farming operations and secondly the means of communication were inadequate. Furthermore in contrast to aviation forecasting, there was a very limited opportunity for amendment which meant that the occasional errors could rarely be corrected before they were operationally significant. One thing seems certain:- after reasonable experience but with restricted scientific qualification it is possible for a forecaster to reach a fair standard of efficiency. If the scientific qualifications (and presumably the scientific ability) are increased, there does not seem to be an equivalent increase in the accuracy of the forecasts. As far as special local forecasts for agriculture are concerned there seems to be no valid argument for the employment of highly qualified scientific staff.

In regard to the different countries, although France seems to issue a large number of special forecasts, there did not appear to be many for agricultural purposes, chiefly because the means of dissemination were so difficult. The French attitude to the issued forecasts was refreshingly realistic and may be summed up conveniently by quoting their own comment on their long-range forecasts "at least they are better than Old Moore's Almanac". The public attitude to the forecasts also seemed to be more sensible; there was less chance of any forecast error being regarded as a personal insult.

Agricultural Australia was extremely interested in the weather forecasts, especially in rainfall prospects. The rain in the grain areas has a very big effect on yield and the newspapers (and Post Office notice boards) give large amounts of space to detailed rain reports. Rapid changes of temperatures, known as 'cold changes' (I have experienced a 30°F drop in temperature in less than an hour in Melbourne) are also of considerable agricultural significance, especially during sheep shearing time.

In most countries no charge is made for forecasts, or a very nominal fee is levied. In Sweden, however, considerable sums are charged for services such as providing a recorded forecast for the Telephone Company (available to the public by dialling a special number) or for forecasts to the equivalent of the Forestry Commission. Half the money so received comes directly into the Meteorological Office funds and can be used to extend the services.

In countries with diverse topography such as Norway and New Zealand it is almost impossible to sub-divide the forecasts so that each individual valley gets the due consideration of its local weather. There does not seem to be any solution to this problem except by educating the local inhabitants so that they can interpret the general weather in terms of regional characteristics. This need for education runs throughout the public meteorological services and I do not think any money sensibly spent in this direction is an extravagance from the national point of view.

In flat countries, such as Holland, the problem is easier. There is a fairly uniform gradation of climate from seaboard to inland and from north to south: the largest agricultural changes come with the transition from the sandy soils to the alluvium and reclaimed polders. This absence of complexity makes possible a type of functional weather forecast coupled with agricultural advice which is broadcast from the Central Forecast Office at De Bilt at 5.30 and 6.30 each morning. The forecast and advice are prepared by a member of the Meteorological Office who was formerly an agriculturist; he is in constant personal and telephonic communication with the agricultural advisory services and research institutes. Such a service needs careful handling, especially in the initial stages, but sensible phrasings of the bulletins can soon generate confidence and I think the idea is not only good but successful.

For various reasons, not all meteorological, it seems very difficult to improve either the accuracy of forecasts or the means whereby they can be communicated to individual farmers in a helpful form. However, one defect can be remedied at very little cost, and that defect is the low level of meteorological knowledge. There is a widespread interest in the subject and it should be possible to improve the knowledge and satisfy the interest by increased facilities for simple lectures to farmers' societies and young farmers' clubs. Increased knowledge will enable more use to be made of available information and must help to raise the level of appreciation.

7. Forest Fires and Floods.

At first consideration it might be thought that these two types of catastrophes have little in common, but from a meteorological point of view they have certain similarities. In both the weather factor is extremely important and yet in neither can explicit forecasts be made; all that can be done is to indicate the degree of risk. Neither calamity can be prevented but adequate warning and defence preparations can contain the spread of the damage. Defence organizations are too expensive to maintain continually so that the duty of the meteorologist is to provide information so that the defences are

alerted a minimum number of times and yet sufficiently frequently never to miss a serious outbreak.

There are many methods in use throughout the world for assessing the fire hazard ranging from the weighing of sample sticks taken from the forest floor to formulae which take into account recent and current meteorological data: in Sweden a method has been used which involves lighting a meta-tablet on the ground and observing the spread of fire in a test area. In all cases three points have to be considered, the state of the forest litter (or prairie grass), the possible chances of ignition and the conditions likely to cause rapid spreading. The reason why meteorological help varies considerably from country to country is that the first factor can probably be assessed with adequate accuracy by foresters without access to meteorological data. The starting cause of the fire is often non-meteorological; in Sweden it was estimated that one third of the fires were caused by railway engines, one third by human carelessness and one third by lightning strikes. In extreme cases of hot dry weather in Australia, 'blow up' conditions are reached when spontaneous combustion may occur especially in the eucalyptus forests. Current meteorological conditions are of paramount significance in regard to the third factor and accurate forecasts can be of great value in the direction of the fight against the fire: a bad or misleading forecast can be very dangerous. The Australian Forestry Service broadcasts relevant weather advice and reviews of the fire hazard on special wavelengths three times a day during the summer. Many countries ban the lighting of fires in the open when the fire risk is high. It is only natural that the organization and meteorological help are most efficient when the dangers are most frequent, but I know that in small countries like Cyprus a direct personal link between the forester and the meteorologist has resulted in reduced fire losses. There has been limited international consultation in meteorological circles on fire-risk assessment and considering the potential economic loss caused by fire and the predominating meteorological influences it is suggested that it is a subject which deserves greater meteorological consideration in some countries, and greater consultation between countries.

There are three main types of floods, those due to sea-water encroachment, snow melt and excessive rain. Holland is the country which has suffered most from flooding by salt water and naturally it is the country where most action is taken to combat such danger. Most of the 1953 floods started with a break through of the sea on the lee side of the islands, and to prevent a recurrence of this catastrophe it is planned to seal off almost all the mouths of the Scheldte. Another future plan is to link up along the line of the Frisian Islands. The rapidity with which the Dutch can rehabilitate land which has been flooded with salt-water is astonishing and their huge reclamation schemes have doubled their area of first-class agricultural land. Due to their unparalleled experience, the art of water control is very highly developed in the Netherlands.

Similarly the questions of snow-melt are carefully studied in Scandinavia and the hydrological section in Sweden, for example, plays a large part in solving the hydro-electrical and water-supply problems. In countries where power is obtained to a large extent from water it is obvious that flood control is a major problem. It has, however, been found that meteorological forecasts, whether of chances of melting or of amounts of rainfall, have not been of sufficient accuracy to permit of their quantitative use. Flood control depends at present largely upon the accuracy and efficiency of a reporting system.

Accurate forecasts of rainfall amounts would not provide the whole answer even if they were available. Knowledge of the terrain, the state of the ground, the soil moisture deficit, the rate of rainfall and the rates of absorption and the run-off would all be needed for a complete picture. Urban floods are usually of short duration and are due to a combination of heavy rain, rapid run-off and small street drains. Country floods are often more serious and have more lasting effects. A meteorologist can only help a River Control Board on this problem; he cannot provide the whole answer. The initial attack on any flood problem must be empirical rather than fundamental and close local liaison is probably of more immediate use than interchange of international experiences.

8. Frost.

The effects of air frost are so immediate and obvious that it is not surprising that it is the subject of many investigations in almost every country. It is not always realized that frost can be of serious economic consequence to the vineyards in the Midi as far south as Montpellier and that the severity of frosts as far north as Central Otago in South Island, New Zealand can exceed those of most of England during the fruit-blossom period.

The first duty of a meteorologist is obviously the consideration of the liability of various areas to frost. Considerable work is being done in Germany; meteorologists are carrying out field surveys and in drawing up charts which indicate the area most prone to frost. Precision is obviously impossible but use is made of local knowledge and experience as well as a scientific appraisal of the topography and the results obtained have a definite practical value. Interesting examples of frost hollows were encountered in Australia where clearances in forests have created conditions under which it was impossible for young trees to grow; the clearances were, in effect, self-sterile. This state of affairs occurred also under natural circumstances in the Australian Alps; the floors and lower slopes of bowl-like upland valleys were devoid of trees which flourished on the higher slopes. Examination of temperature profiles showed that it was almost impossible for young trees to survive the low temperatures observed at night in the lower levels of these natural arenas.

Owing to the local variations in night minimum temperatures and the knife-edge nature of the frost threshold, the forecasting of frost is full of difficulties. Some measure of success is attained over flat country but in broken or hilly districts nothing but the most general of warnings can be expected. This degree of uncertainty is most considerable when the conditions are border-line and the economic significance is greatest; cases in point are the last frost in spring or the first frost in autumn which are unlikely to occur in easily forecast conditions. As forecasts are unavoidably fallible, many areas rely on frost alarms which warn the grower when the temperature falls to a pre-determined value.

This idea has been extended in a frost club at Mildura (Australia). The alarms are set at the sites most liable to frost and warn a small frost committee of three of the most experienced members; the committee then decide whether the occasion warrants the awakening of the 30-40 other club members. The system seems to work well but obviously demands considerable mutual trust.

Most countries issue advice about frost avoidance and stress the importance of site selection and air drainage; Australia, more than most, emphasises also the help which can be gained by keeping the soil moist, compact and free from weeds. The effect of these cultural practices is small numerically but is very significant in the lower layers of the atmosphere in areas where the severity of frost is not great; these practices are therefore most useful in vineyards, but they are also helpful in top-fruit areas.

In regard to frost-protection methods it is perhaps not an unfair summary to refer to the fact that New Zealand had invited suggestions for new ideas; over 100 were received, none of them being economically successful. Oil burners are the most common protective weapon, and indeed, they give reasonable protection in light frosts but demand considerable man-power. If the number of times they are used increases they soon become uneconomic. Both France and Australia were examining the probable efficiency of water-fogs, paying special attention to the drop size, but the degree of protection was not likely to be high. Artificial fogs tested in Germany had limited success, and no fog method seems suitable for orchards. Protection by water sprinkling had been tried in Norway, Holland and Germany and this seems to be a promising method over limited areas with quick draining soils. Frost propellers met with varying success in Germany, New Zealand and Australia. The presence of low inversions and the prevalence of slight frosts in the last-named country seemed to suggest that their quickly moving fans with rotating jets of air might prove to be satisfactory. Holland has been investigating the effect of protective cover using different materials. The thickness of the material seems to be more important than its type.

Although spring frosts steal the headlines they are not the only ones which are of importance. Belgium has been investigating the damage to autumn-sown cereals by winter frosts, the importance of snow cover to protect the crops and the relatively slow penetration rate of cold through the snow cover were significant points. Winter frosts can also cause extensive "frost-heave" damage to roads with shallow foundations and the damage in 1945-55 in Germany was very extensive indeed.

9. Glasshouses.

In theory, all the environmental factors in a glasshouse are under skilled control. In practice this is rarely true and even if a degree of control is exerted it is not always certain that its effects are completely beneficial. As a glasshouse represents a very large investment of capital and as running costs are always on the increase, it is natural that more and more attention is being given to the scientific aids to glasshouse management.

In the most general terms the obvious problems are keeping the glasshouse warm enough in cold weather and not letting it get too hot in warm weather. The major factor in the former problem is one of throughput of air or effective elimination of draughts - the reverse of ventilation. In the second problem, the distempering of the panes, the use of water flowing over the house from a ridge source, louvred blinds or even direct air conditioning have been used, to keep the interior air temperatures at a reasonable value. In extreme cases the glass is no longer used and the house becomes one of bamboo slats; this cuts down the direct incoming radiation and the inside temperature is very little different from that of the external air. This is extremely useful when experiments are in progress concerning young plants which cannot stand the intense heat of continual direct sunshine. (e.g. in South Africa)

In more temperate climates, winter illumination is probably far more limiting in its effect on growth than has hitherto been realized. This deficiency must be overcome artificially or by making the most use of natural light. In this connection a kind of frosted glass has been under test in Germany and their results suggested that more light was transmitted than through the usual horticultural glass so that yields under Dutch lights were greater. I saw this glass under test at De Bilt, Holland, but so far no conclusions have been reached there.

Plastic films are now being used to double-line glasshouses during winter and I saw a "De-dutchable" house at Bonn where the panes were wholly constructed of one of the new plastics; previous experiments with similar materials elsewhere had indicated a drop of light within such a structure which increased as the material yellowed with age and was scratched in use. This new plastic seemed free from these defects and was very durable and relatively cheap. It may yet be an answer to the breakage of panes by hail or by "sound-barrier" shocks.

The Belgian Institute at Uccle were conducting a series of experiments on glasshouse climate and the Germans had tried out a new form of temperature regulations in an electrically heated house. This depended on a predetermined link between illumination and optimum day temperature. An illumination-meter was geared to the thermostat which controlled the heating in a small test house. No great increases in yields were apparent but the fuel consumption was very much more economic.

Difficulties in glasshouse work are largely concerned with radiation and illumination measurements and with assessments of ventilation or air changes. As in other spheres of agricultural meteorology there is also a hiatus in the links between plant climate and growth and plant climate and disease. The investigator is thus uncertain as to the climate he requires apart from the problem of how he is going to maintain it.

10. Illumination and Radiation.

There was no intention of making a survey of the types of instrument used throughout the world for the measurement of these very important factors, but of the installations which were encountered, by far the most extensive was the one

on the 'tour du rayonnement' at Uccle, Brussels, where considerable use was being made of batteries of instruments and thread recorders. From various discussions, however, it was evident that the importance of such measurements was being increasingly realized, especially in those countries which did not have much sunshine data available. The Campbell-Stokes instrument, reliable and helpful though it is, has obvious limitations and it is interesting to note that there is a 10% change in recorded sunshine hours as you cross the Dutch-German border because of the different standards of assessment of the burns on sunshine cards.

Although the need for extra measurements was acknowledged, the supply was by no means easy. Such instruments as are at present available are neither cheap nor robust, and in some cases are not particularly accurate when used continually without proper calibration and supervision. As a result they can only be used at stations or observatories where they can be treated with due care and attention; they cannot be regarded as available for semi-skilled use under field conditions. From the agricultural point of view there is the added complication that not only do research workers appear to use the terms illumination or radiation indiscriminately but also that they are by no means certain what exact measurements are significant for their purposes. This is clearly a case where co-operation is needed between biologists and physicists at the fundamental level.

An interesting case of the importance of radiation arose in South Africa where trouble is sometimes encountered in the delayed foliation of fruit trees. This trouble was least in the case of trees which were shaded from winter sunshine. Examination of the microclimatic factors in the orchards suggested that excess winter radiation was a very important criterion. This could be traced in the more general case by the higher mean temperatures in the winter months when radiation was excessive; an effect of radiation was thus recognized by examination of the temperatures. Other work in South Africa traced injury to peach twigs to the effect of sudden increases in ultra-violet radiation.

Some work discussed at Adelaide, South Australia, suggested that a limit to the crop yield with increasing density of shade was provided by the fact that there was a point reached when the crop shaded itself. This limitation appeared to be one of incoming energy, and not competition for moisture or nutrients in the soil.

It has been obvious for a long time that temperature alone was an insufficient guide to crop yields or crop development, although in areas where radiation and temperature are closely related consideration of temperature inevitably involves radiation as an implied factor. This problem of combining effects of temperature and radiation to give an empirical expression to be linked with crop growth is being tackled in France where the product of temperature and the square root of the radiation has been suggested as a parameter. Experiments are now in progress at Versailles, Montpellier and a mountain station, to examine the growth of wheat under various radiation and temperature conditions. The period of a crop's life between emergence and maturity should be expressible, for any one variety, in terms of meteorological factors. Accumulated temperatures have been found unsatisfactory for this purpose, but introduction of a radiation term should lead to better results; there are also indications that a transpiration term (a function of radiation) can help in yield correlations. It is probable that most work concerning illumination and radiation will be done in relation to problems of the glasshouse industry, mainly due to the large capital involved and the necessity for increased efficiency in the provision of artificial climates.

11. Irrigation.

For a long time, in most people's minds, irrigation was thought to be important only in arid or semi-arid areas. Nowadays there is an increasing interest being taken in the subject in areas which hitherto were regarded as of moderate to high rainfall and in application to crops which show an appreciable response to controlled moisture supply. Rainfall may be adequate on the average, or in the season as a whole, but unless it is both adequate and timely throughout

the growth period maximum yields cannot be obtained. In the words of the title of the French booklet on irrigation the importance is summed up as "La pluie à vos ordres".

In areas where there is very little rain, and where no cultivation at all would be possible without additional irrigation, many extensive irrigation systems have been introduced: typical examples are parts of the Canterbury Plains in New Zealand and large areas in the Riverina and Murray River districts of Australia. The water is conveyed to the area via rivers, canals and ditches and is generally available on a roster system with a limit to the amount delivered at any one time at any one season. Application is generally by furrow or flood methods. Although spray irrigation is common in private gardens, it is the exception in the fields owing to the limited available man-power. Once roster systems have been established and feeding channels constructed in accordance with the system it is extremely expensive, if not impossible, to make any changes. The ideas of the original planners are thus forced on the present farming generation. This was neatly expressed by a member of a New Zealand Irrigation Research Station (Winchmore); "We get water every second Tuesday, so it is no use talking about optimum intervals between irrigations".

I gained the impression that the total amount of water which was allocated to each farmer was confirmed by recent research but that it had now been realized that it was better to put on weekly water rather than fortnightly. Large gaps between water led to over-watering at any one application in the vain attempt to force more water into the soil to see the crop through the next fourteen days. This led to abnormally high water-tables and much salt trouble. The best farms I saw in Australia were those where water was added by sprinklers at a much slower rate and at more frequent intervals than was the usual practice.

At one farm, Badgery Creek, attached to Sydney University, about six or seven reservoirs had been constructed using earth dams. By this means all the rain falling on the 400 acres was collected in the reservoirs which cover 40 acres; water from nearby creeks was also pumped into the storage whenever possible. From this supply 100 acres of grass are spray-irrigated and the output of dairy products is now higher than it was from the whole 400 acres before the irrigation was started. This successful local action is helped and made possible by the topography of the farm, the low penetration rate of rain into the soil and the rapid run-off, and finally the fact that the rainfall is built up by short intense falls of the thunderstorm type.

Increased local storage of water may be the key to many irrigation problems in Britain because the public mains supply is not the ideal method of distribution. Farms only require water for part of the year and are therefore not ideal customers especially as the demand tends to be greatest when stocks are lowest. It is a matter for field experiment to determine how much land can be used economically to store water which is to be used to increase the yield from the remainder. The economic criterion is of paramount importance in all practical irrigation problems and this is the reason why many experiments have been of the "ad hoc" nature. Nevertheless, meteorological data is often lacking concerning experiments and this makes it almost impossible to compare them. Interpretation even in the local area may be difficult unless adequate weather data are recorded. On more than one occasion I have come across field experiments during which not even the rainfall was recorded. It is true that adequate response to irrigation can be obtained by relatively crude rule-of-thumb methods and that extra care will not in all cases bring sufficient extra yield to compensate for the additional expenditure. Notwithstanding this it is evident that weather is the major uncontrolled critical factor in designing irrigation practice and therefore must be considered in field experiments as well as in fundamental research. Conversations in Australia and New Zealand proved that both water engineers and agronomists were using meteorological knowledge and statistics in assessing water needs to a greater extent than hitherto, but the final factor is always the financial one.

The first duty of the agricultural scientist is to ensure that irrigation is not harming the land; the second duty is to help to provide working rules which have a fairly universal application in a simple form. No matter how

precise and intricate the initial experiments may be, the final advice given to the farmer must be in units which he is capable of using and a form which can tolerate the margin of error that inevitably arises in field practice. A high degree of precision can sometimes be reached in field conditions, an example being the control of the water-table in the Dutch bulb-fields and polders, but this is the exception rather than the rule.

The general principles underlying successful irrigation are common to all conditions. It is important to ensure that the plants or trees do not suffer a moisture check at any time during their growing period otherwise subsequent watering cannot completely eliminate the effect of such a check on the yield. This, however, does not mean that the treatment which will ensure maximum yield will also bring about optimum quality. Both taste and keeping quality may be affected by moisture conditions during growth. Much more experience is needed in these questions but irrigation has so many obvious immediate virtues that the finer points may take some longer time to establish.

In the meantime, experience in many countries has shown that the Penman method of using meteorological data to assess irrigation requirements is of a sufficient degree of accuracy to be of considerable help in interpreting experimental results, as a guide to current practice or a basis for long term plans.

12. Land Use and Plant Introduction.

In countries with a long history of increasingly efficient agriculture the problems of land use have usually been solved by a progressive system of trial and error. The result is a fairly stable farming pattern in which variations only occur for economic reasons. This is especially the case in small countries where land is limited, for example in Denmark or Holland. In large countries such as France or in less densely populated ones such as Eire, there has been less compulsion of circumstances to bring about this state of affairs. In countries which are undergoing a type of agricultural revolution, such as Germany, or which are in a state of initial development, such as parts of Australia, the problem of land use is far more urgent, and it is a problem in which the meteorology must be fully and correctly considered before the right answer can be obtained.

In Australia, new territory is surveyed by a small team of scientists, one of whom is responsible for the meteorological appraisalment. Owing to the shortage of trained field staff it is not normal for a meteorologist to be one of the survey team, but special climate bulletins are prepared for specific areas and for specific types of land use. The efficiency of these surveys has improved considerably as more experience has been gained and it is remarkable that mistakes in land use made in settlements opened up after the 1914-18 war have not been repeated in 1945 onwards. Some of the more recent settlements were some of the most suitable and the most efficient; in many ways the same could be said of New Zealand although in that country the difficulties were less in that the climate was very much more of a friend than an enemy.

Errors are often made in the over-rapid development of a country and the search for the explanation of the failures is often a very common approach to increased knowledge. A case in point is the consideration of the climate factors in fruit and vegetable growing in South Africa. Knowledge of plant-weather relationships is often found when a limit of cold or warmth, of wet or dryness, has been passed with resultant crop failures. In Sweden, for example, no tobacco plant in 1954 advanced beyond the ground rosette stage, the first time this has been known to happen: the warmth of that summer in southern Sweden was just insufficient to permit growth.

Mention has already been made when considering erosion of the major errors of land use - corn in too dry an area, or poor grass in too wet a mountain area. In both Australia and New Zealand more care is now being taken to avoid repetition of such errors, but it must be realized that a small variation in rainfall climate can cause a big change in the 'wheat line' across a semi-arid

country. Similarly an unusual heavy rainfall can cause immense damage even though it occurs only once.

A problem of land use in Germany, and to a much smaller extent in Holland, has arisen because of the system of land inheritance. This system demanded the sub-division of a farm on the death of the owner between the sons and the result is a pattern of strip cultivation and the farming of widely scattered strips. This is a very uneconomic process, especially when in Bavaria the usual form of farm transport is a wagon drawn by cows. This type of farming, which was common in pre-enclosure England, is now being altered by the exchange of land and creation of farm units. As might be expected the process is not an easy one and leads to considerable disagreement concerning the relative value of strips of land. In the assessment of this value the agricultural meteorologists are consulted. They are also consulted in regard to the land use and the planting of hedges or shelter in the new composite farms. In a similar way they are also asked in Germany for advice regarding the siting of sanatoria - not an agricultural duty in itself, but one which enters into the complete picture of country planning.

Even in countries where there is no major land change or land development taking place there is always a considerable amount of introduction of new plants. As no two places have exactly the same climate this is always in the nature of a gamble. Much has been written on the subject of climate homologues but until the plant's reactions to climate are understood completely, strict comparisons are impossible. I do not greatly like any system of climatic indices although Thorntwaite's attempt to consider rainfall and evapotranspiration does appear to have some logical sense in its argument if not in its precise arithmetic. I cannot see plant introduction progressing much beyond the intelligent guess or trial-and-error stage until we have a greater knowledge of the link between meteorology and plant growth.

13. Phenology.

The recording and analysis of phenological data is a fascinating subject which has attracted nature lovers and natural historians for a hundred years or more. The organization of extensive phenological networks dates from the optimistic mid-nineteenth century period when it was hoped that increased accumulation of data would automatically result in the increase of knowledge. It was considered that the movement and growth of animals, birds and plants were an integration of past and present weather and I am not at all sure but that in some cases there was the hope that such facts could act as a sort of weather forecast. The ultimate aim of the enthusiasts is a world network involving every country, a universal list of standard plants, and the extraction of isopleths. The argument that wild plants, uninfluenced by man, can act as our weather observers is an attractive one, but unfortunately it has not produced any major contribution to meteorology or even to climatology. Even if we accept the inevitable plant to plant variation within any variety and hence the non-standard calibration of our chosen measuring instrument, we are still faced with the problem that a map of the dates of the first snowdrop is no use so far except as a map of the dates of the first snowdrop. Germany has easily the finest network of phenological observations but even they cannot yet claim a value for their excellent maps of (wild) phenology except as a self-evident representation of an ecological fact.

This, however, is not the whole story. Part of phenology deals with cultivated crops and with farm operations; it could be extended to include the epidemiology of plant (or animal) disease. Facts of this nature have a direct operational and economic importance. In so far as they indicate such things as growing seasons they have a degree of climatic importance but it must be remembered that a continental map of the time of wheat harvest is concerned with dozens of varieties of wheat. Details collected concerning farm practice cannot but help to facilitate agricultural planning and to elucidate problems of land use. They should be of help in establishing the links between climate and agriculture, but the practice of using arbitrary calendar climate data in terms of weeks or months cannot accelerate such establishment. The calendar of a plant is the calendar of sowing, emergence and maturity, and climatological

data should be referred to the phenological base-line. Such plant calendars are naturally kept in plant-breeding or variety-testing records.

Besides the extensive German network of phenological reports which include both the types discussed here, an increasing amount of detail in the Netherlands is being acquired concerning the farming calendar and disease incidence. The Dutch use such data in connection with the wireless weather forecasts and the broadcast farming advice. The French also keep a fairly close check on disease phenology; they are also paying considerable attention at Versailles to increased accuracy of the phenology of fruit to eliminate the degree of uncertainty in the system of observations.

If there is any future development on what might be called traditional lines it will probably emanate from Germany but I feel that the next few years are more likely to see increased activity in the more modern modification of the phenological type of observation. In particular, knowledge of phenology of plant diseases is essential before meteorology and climatology can help pathological problems.

14. Plant Breeding.

The meteorologists' contribution to the problems of plant breeding lies principally in the interpretation of the performance and yield in variety trials. Because we are relatively ignorant of the exact way the weather affects growth of plants this problem is a very difficult one. It was discussed in many countries including Eire, Belgium, Sweden, Denmark, New Zealand and South Africa. New varieties must be tested before they can be approved or recommended and must be tested quickly; a decision has generally to be reached after three years of field trials. The usual procedure is to carry out a test at the research station (or stations) and then further tests at a limited number of trial centres. One old variety is grown in each trial as a standard of comparison. If a new variety fails badly in any one year it is almost invariably discarded. Second chances cannot be given when there is usually a host of other promising strains awaiting trial. If a good variety is found the extent to which it can be recommended (the zoning of the seed) is still doubtful; the stations where it has been tested may be chosen to provide a fair soil and climate network, but the years of trial may not have been a fair climatological sample.

Two ways of help seem advisable. Firstly the meteorologist can offer very pertinent and useful advice concerning the uniformity of local weather over the trial plots, especially in regard to aspect and exposure. Secondly, despite lack of precise knowledge he can help qualitatively in the assessment of field results. It is very important that he should try to do so because it is certain that the year-to-year yield variations due to weather are generally greater than the plot-to-plot variations due to variety. The plant breeder and trials officer can also help the meteorologist because they have a unique opportunity of recording the exact phenological stages of crops under trial. If at the same time weather records are obtained it is possible that such data can be used to further our limited knowledge of crop-weather relationships.

15. Plant Pathology.

The incidence of pests and diseases play a large part, and in some cases a predominant part, in the determination of crop yield. This incidence is largely controlled by weather conditions; the fight against the pest or disease is affected by possible predators, by the weather, and by the action taken by the farmer or grower. Action against disease is usually in the form of spraying and such spraying may be protective in nature or have an eradicant action. It is necessary that such defensive or offensive action should be both effective and economical. Experience in many diseases and in many parts of the world shows that such success can often only be accomplished by due consideration of the weather factor.

The French have summed up the main requirements as follows:-

- (i) Thorough knowledge by the biologist of the life-cycle of the parasites.
- (ii) Precise knowledge of the evolution of the host-plants.
- (iii) Most precise knowledge possible concerning the effects of weather conditions upon the evolution and growth of plant enemies.

This precise knowledge must first be discovered by specialists working at or from a research station. Thereafter such knowledge must be used with the object of providing a system of agricultural warnings to enable the farmer to protect his crops efficiently. This demands an intelligence system and, in reverse, a warning system.

The French organization under the Plant Protection Division of their Ministry of Agriculture has 12 regional centres from which agricultural warnings are issued. The regions are chosen for climatological reasons rather than for administrative purposes and were described as "phyto-pathological zones". The centres receive phenological data from districts and also have a network of meteorological observers who send in data which is simple in character and of an accuracy below that demanded from a climatological station but adequate for the required purpose. Using criteria determined by the research stations, these centres can now issue advice and warnings by press, radio, and especially by post. I understand that their postal service, for which a small charge is made, is growing steadily in extent. Each centre has a fully equipped meteorological station, of the normal standard, where there is sufficient adjacent land to use as an observation post for test bodies of plants and parasites; for example, cages around the trunks of apple trees enable the hatch of pests to be observed. It is difficult to assess the efficiency of such an organization but it has been estimated that the spraying of vines by copper sulphate based on such meteorological-pathological advice can lead to the decrease of 50% in the number of applications - a saving of one and a half million pounds in spray material alone. Much, however, depends on the efficiency of the warnings and the trust the individual farmer has in the organization - a trust that can only be engendered by success, by education, and by honest publicity.

The importance of successful disease forecasting was recognised by the Commission of Agricultural Meteorology of the World Meteorological Organization and a working party (of which I was a member) was formed with Mr. Bourke of Eire as Chairman, to examine relations between meteorology and potato blight and the work which had been done to combat the disease. Advantage was taken of the visit to Southern Ireland to examine the material that had been collected in this investigation, and thanks mainly to the energies of the Chairman the report of this working party is now published. The lessons to be learnt from its findings are of great importance:- firstly it is clear that collaboration between meteorologists and pathologists can lead to consequences of considerable national economic importance: secondly semi-empirical or approximate methods of approach can attain success provided that such approaches are suited to the peculiar climatic limitations of the area; absolute knowledge is not essential: thirdly it is clear by implication that there is a very limited area of the globe in which there is a high standard of disease and weather measurement. A tendency to think in terms of the standards of the English-speaking peoples and the western nations of Europe can be very, very, misleading.

There is increasing interest in Scandinavian countries on this dual problem possibly accelerated by the wet summer of 1954 which was disastrous from the fungus disease point of view. I have rarely seen such potato fields ruined by blight as I saw in Sweden, they resembled the description of the Irish fields in the 'Famine' days. I understood that in Germany the link between pathologists and meteorologists had been rendered difficult due to post-war disposal of centres of organization but I did see at Heidelberg a sample bed of Colorado Beetle that were being watched by the meteorologists to determine their date of emergence.

Beyond a doubt the work on this subject in Holland is outstanding. This is the result of several diverse causes. Marshall Aid has helped in the building of several new technical and research institutes at Wageningen, an aspect of reconstruction which can be described as investment. At Wageningen is also the headquarters of the Plant Protection Service: not far away at De Bilt is the headquarters of the Meteorological Service, which has a relatively large agricultural section. Holland is small in area and has fewer local variations in climate than most countries. The country is also fully aware of the importance of agriculture.

Conditions are thus favourable for an efficient service. There is a good system of phenological intelligence and as the weather forecasts, sent from the Meteorological Office, contain agricultural advice, there is also a good warning system. The conditions for potato blight are now so fully tested that the initiation of the warnings is solely a meteorological matter, using criteria established by joint research. Apple scab is a disease which is being examined with a similar end in view; at present the joint investigation is proceeding on a part-research, part-operational basis. The intelligence channels of the Plant Protection Service and the disease phenology of the Meteorological Office, plus constant personal or telephonic collaboration facilitate the reporting or issuing of advice on other pests and diseases. The best is obviously made of the favourable conditions.

16. Plant Physiology.

Knowledge of the relation between weather and plant growth is very important to agricultural meteorology, but the subject is a very difficult one and the extent of our knowledge is very fragmentary. Progress in this direction demands research at the fundamental level and this involves experience both in microbiology and microphysics. It is therefore not surprising that the bulk of the work is done by plant physiologists who have some meteorological background or training.

Such a type of research officer is in existence in France and opportunity was taken to discuss problems of this nature both at Montpellier and Versailles. In South Africa, there is a research physicist stationed at a Fruit Research Station; this enables work to be done in collaboration which would be impossible, or at least very difficult, in isolation. Research of this nature can be concerned with accepted or proposed husbandry techniques (such as oil spraying), with problems of land use, or with the important questions of yield forecasting.

Research officers at agricultural stations can introduce special meteorological observations for the purposes of their investigations, but often problems have to be attacked making use of the available standard data. Accumulated temperature is a parameter which has long been a favourite in any attempt at establishing a growth-climate relationship. I met several people who would condemn it outright on logical and physiological grounds, but it was also pointed out that there was little else one could use and that it was possible to attain a fair and helpful degree of accuracy. The great mistake would be to assume that anything superior to a "good working indication" could be obtained with such crude data.

The statistical approach is a promising one under certain circumstances. There is nothing quite so dangerous as a little knowledge of statistics and even the best of statisticians can only work as well as his available data allows. When one meteorological factor is more important than all the rest and especially when it is a direct factor such as rainfall, useful results can be obtained, but even then it is difficult to separate the effect of rainfall from the effects of the weather which is associated with rainfall.

Furthermore, statistics are probably more useful in a negative sense than in a positive one. If they establish that two variables are independent or that their apparent relationship is within the bounds of chance, a valuable negative result has been obtained. If they establish an apparently firm relationship, such a relationship has still to be explained.

The future for meteorological assistance to the solution of problems of plant physiology must be twofold. Help is needed in finding the complete answers to questions of biological growth, and yet some approximate answers must be found for use on a practical scale until the absolute truth is attained.

The forecasting of crop yields is a matter of considerable economic importance and at present the estimates are often bedevilled by what might be termed "not entirely disinterested guesswork". The net result to the farmer is not always what he intends it to be and the net effect on the housewife's purse is sometimes serious.

17. Shelter.

The first example of shelter I met with during the tour was in the Rhône Valley. In that area the Mistral was so strong and frequent in its occurrence that every plot of vegetables or non-hardy crops were protected by a fence of thick reeds some 6 ft. high. It was an excellent example of something being done when the problem was serious enough. In less obvious cases of wind incidence, shelter is often ignored and only noticed when it isn't there, or after it has been removed; it is rarely consciously introduced.

In Norway and Sweden, shelter seemed to be more of a subconscious reaction against cold winter conditions, rather than a deliberate plan; perhaps the density of tree cover rather influenced this impression. The snow fences on the Bergen-Oslo railway were the striking examples of deliberate interference with wind and its effects.

In Denmark the picture was slightly different as land shortage had led to reduction in the area given to hedge boundaries and shelter. There were indications that some authorities considered that this process had gone on too far but I did not have the opportunity there to examine the work being carried out on the effects of shelter.

In New Zealand considerable tree shelter is seen around farmsteads and possibly this is due to the fact that this country was not so long ago covered with trees and the problem has been rather to get rid of them than to plant them. Trees have thus remained in certain areas to save cost of removal, but there also was definite evidence of planned tree belts. The general value of shelter seemed to be generally accepted in this country. In Australia trees seemed of more value to provide shade, although some form of shelter was appreciated by graziers for their sheep immediately after shearing.

The countries doing most investigational work concerning shelter were Holland and Germany. The exact determination of the economic value of shelter is very important in the Netherlands because there is a great shortage of land and the flat nature of the country is conducive to strong winds. Laws in Germany forbid the removal of existing hedge systems and special plans are made for providing additional protection against wind when fragmented land is being reallocated.

Analysis of the magnitude of the wind danger is carried out in Germany both in the laboratory and in the field. Scale models of the countryside are placed in a wind tunnel at Giessen and the flow of air is examined by various devices. It was at first thought that such models would only be of use in regard to wind direction and that scale difficulties would distort the magnitude effects. In practice field work following the wind-tunnel experiments has confirmed the results to a degree which has surprised the investigators.

The field work is usually carried out on a limited number of days by a team of observers. One central reference point is established and a recording anemometer is placed there. The team then cover the area with portable anemometers and short-time runs at various places are weighted with respect to the central reference point values to obtain a picture of the wind field. From such surveys decisions are taken as to the parts of the area which are most in need of additional protection. The efficiency of such surveys obviously increases with experience.

Experiments are also in progress at Heidelberg concerning the protection of market garden crops with movable wind-breaks such as chestnut palings, hessian or netting. These experiments are similar to the ones in progress in Britain and much the same type of result is being obtained; the experimental difficulties are also very similar, plant disease and crop establishment being a conspicuous bugbear.

It is a thought-providing fact that the taking of numerous meteorological observations in the vicinity of some form of shelter does not appreciably add much to our precise knowledge of the practical agricultural effects. The link between weather and plant growth or weather and animal welfare is still too tenuous for any firm conclusion to be drawn from the wealth of physical statistics. In many experiments the plant or the animal must be taken as the yardstick for want of a better scale of values.

18. Soil Physics.

Soil physics is not strictly part of meteorology, but agriculture is concerned with both air and soil, so that the agricultural meteorologist must at least be aware of what is happening in the subject. Soil temperatures have, in fact, been part of the observing routine of many countries for a long time. Observations of soil moisture are far less common, for the very excellent reason that there is no convenient and accurate method available to make the measurements. Soil physics also has to concern itself with questions of the air or carbon dioxide content of soil and properties which make up that somewhat vague term "soil structure". In regard to the nutrients in the soil, these principally lie in the realm of the soil chemist, but it is very interesting to read of this subject from the point of view of the mathematical physicist and the Wageningen paper on Fertilizer Placement was, to me, unique. Even so, it was yet another example of the principle that a scientist trained in a certain discipline can often use his techniques to good advantage in work in a related subject.

Analysis of soil temperatures is not easy, because the rates of thermal diffusion in the soil are so dependent on the state of the soil, especially the soil moisture. The extent to which agricultural operations, such as hoeing or ploughing, effect the distribution of heat in the soil is a matter of considerable significance but work of this type is by no means common; a recent Dutch paper on the effect of tilth gives some very interesting results, especially in regard to heat transference upwards at night.

If adequate water is present in the soil, the length of the period between sowing and emergence must be a function of soil temperature, yet again there is little reliable work on the subject. Accumulated soil temperatures may be far more useful to agriculture than accumulated air temperatures. The Dutch are of the opinion that if one knows the temperature-diffusivity characteristics of a given soil, then much can be deduced from a limited set of readings; constant recording of temperature at various depths can thus be avoided. Nevertheless there is a limit to the validity of such deductions and this is usually imposed by the moisture content of the soil.

Soil moisture is a very difficult thing to measure accurately, and there is at present no really satisfactory method. It is not surprising that the British at Rothamsted have adopted a means of calculating a soil moisture deficit and the French at Versailles have proposed a series of typical soil moisture profiles during the drying out or wetting period of the soil.

The latest method under trial is one which involves the measurement of the slowing down of neutrons by the hydrogen ions in the soil; it is being tried in New Zealand, Australia and Belgium; the major practical difficulties are the size of the apparatus which has to be conveyed on a 15 cwt. truck, its cost, which is considerable, and the fact that it cannot measure accurately the moisture content in the topmost soil layers. Nevertheless its use may add greatly to our knowledge.

Another soil property which is very difficult to measure is the extent and dimensions of the air spaces in the soil. The crumb structure of soil is something which gardeners talk about but which has no convenient physical standard of measurement. Work at Groningen in Holland suggests that agricultural soil physics could make use of the techniques and measurements of engineering soil physics. This potential collaboration was also emphasised at a conference in New Zealand.

19. Storage and Transport of Food.

By far the most interesting subject of storage was the German investigation into the climate of the wine-cellar in the Rhineland. The quality of the hock vintage depended to some extent on the conditions under which the wine was kept and considerable differences were found between apparently similar cellars. Constancy of temperature is one essential and this appears to have been attained in the champagne cellars at Epernay in France. This, however, is not the complete answer, for a degree of humidity control is essential otherwise the process of maturing may be affected or the bottle corks become diseased.

This storage problem is of far greater dimensions in South Africa where the Wine Cooperative [K.W.V.] have a much less favourable external climate to offset. Buildings above ground in that region lead to very high storage temperatures and an underground air-conditioned storage has had to be built.

In South Africa also all exported varieties of grapes have to undergo a test to prove that they can withstand 14 days below freezing plus 10 days at 50°F. without loss of quality. This is to ensure that they are fit to stand the sea transport plus up to 10 days between landing in England and consumption. Some of the table varieties do not pass this test and are not exported.

Work in Australia on the keeping quality of apples has led to the suggestion that the temperatures about two or three weeks after set of fruit may be the deciding factor. Considerable work has also been done in that country on the maturity of peas and sweet corn with regard to the optimum conditions for canning.

Cold storage conditions for hard fruit were the subject of an investigation at Bonn, Germany, but damage during storage is only partly a function of the storage conditions and results are difficult to assess if the year has been a bad one for disease.

Many European countries take special precautions to avoid damage to food during transit in frosty winter conditions. I saw few examples of research concerning fodder or grain storage, although the standard Scandinavian practice of hay-drying by use of the special "clothes-line" was much in evidence in the fields. It had long been realized there that wind-rows were useless, whereas in England it succeeds often enough to cause farmers to retain the practice with disastrous results in wet years.

So much hardly-won food is lost in storage that it is strange that more care is not taken. At present the attitude seems to be that some losses are inevitable, but greater knowledge of conditions leading to deterioration and control of storage climate could eliminate a proportion of the wastage.

Conclusions.

Under ideal conditions it is obvious that the duty of agricultural meteorology is to provide the necessary assistance to enable a choice to be made of the best type of farming or land use for any given area, and also to help to discover the correct methods for attaining maximum production in the optimum type. In practice, it is not always that the best type of crop is the crop that present circumstances require, and furthermore maximum production may not be an economic possibility. Thus, although the ultimate aims are clear, the intermediate targets are often chosen by current circumstances. The type of problem in the solution of which a meteorologist is likely to be asked for help, will probably be of considerable local importance and national economic

significance. The level of knowledge of meteorology in agriculture is such that he will certainly be able to give some help in all problems, but there are so many problems and so few helpers that it is essential that the choice of the problem for any major effort is a correct one. It is suggested that the correctness of the choice is determined by the chance of reaching an answer which is adequate to the degree of accuracy required in field operations. In other words, time must not be spent on any problem, however important, if there is little chance of success. Such action is justified only if there are sufficient workers in the field who are already attacking the problems which can be solved. Attacking the enemy where he is weakest is a strategy of long standing.

By this means a limited amount of men and material can have the maximum effect on the economic health of a nation. The different requirements of desirability and practicability do not always coincide, but it is encouraging to note that in two major agricultural problems, meteorology can play, and is playing, a large part. These are questions of irrigation and plant disease, and in both cases correct husbandry can result in yield increases of the order of tens of per cent; in some cases it can make all the difference between a crop and no crop at all.

The need to be able to forecast crop yields may or may not be important, but although it is a question which is often asked, it is one which is very difficult to answer and I am not certain whether there is much prospect of improved efficiency in this respect. The effect of frost is a question which has suffered from over-emphasis by those most nearly affected; the effect of shelter is one which has suffered from neglect. Both are worthy of consideration in any research plan, but I incline to the view that our help is needed most in regard to shelter.

It is also suggested that more thought could be given to questions of the part played by climate on the storage and preservation of food. The losses during storage can be heavy; they should be avoidable. Remedies probably involve long-term planning, and this emphasises a principle to the effect that it is important to give meteorological help to long-term problems which demand a high capital outlay. All the forecasts in the world, even if they were accurate, could not help a farmer if he meets a set of circumstances in which he has not got adequate equipment or adequate buildings.

To the artificial climate of storage we may add the artificial climate of glasshouses and frames. In this subject we need to know more about the weather, especially in respect to radiation and illumination, and a great deal more about the biology of plant growth and the pathology of disease. The area covered by glass in this country is small, but the capital invested is very large indeed.

Erosion is not a very serious problem in Britain, but because it happens only under extreme conditions is the reason why it should never happen at all. Forest fires are also relatively unimportant when compared to the losses in other countries, but they are still, for the most part, preventable. Animal health and husbandry is so far a neglected subject in agricultural meteorology; there is no reason why it should remain so.

In all aspects of agricultural meteorology there is need for help at three levels, at the fundamental level, to discover the essential truths, at the practical level to find the sensible working answer, and at the common level to disseminate help and information. There is much to be learned but there is ample to do using only the data and knowledge that is already at our disposal. The only deficiencies are time and men.

Note:- As stated in the introduction, the bibliography has been arranged to correspond with the nineteen sections in the report. It is not comprehensive; it refers exclusively to papers collected during the fellowship tour. The majority of the papers are now in the possession of the Meteorological Office Library at Harrow (M.O.20); the remainder have been retained by the Agricultural Branch (M.O.19).

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